Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

A99.9
F764U
cop. 3

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Paper
INT-344

June 1985

Woodland Tree Volume Estimation: A Visual Segmentation Technique

J. David Born
David C. Chojnacky

USDA
NAT'L AGRIC LIBRARY
JAN 27 '86
CURRENT SERIAL RECORDS

THE AUTHORS

J. DAVID BORN is a forester, Forest Survey, Intermountain Research Station, Ogden, UT. Before going to Ogden in 1967, he held a similar position with the Pacific Northwest Forest and Range Experiment Station in Alaska. He holds B.S. and M.S. degrees in forestry from Purdue University, Lafayette, IN.

DAVID C. CHOJNACKY is a research forester, Forest Survey, Intermountain Research Station, Ogden, UT. He has been with the Forest Service since 1979. Before going to Ogden, he held a position with the Forest Research Laboratory at Oregon State University, Corvallis. He holds a B.S. degree in mathematics from the University of Idaho, Moscow, an M.S. degree in watershed management from the University of Arizona, Tucson, and a Ph.D. degree in forest biometry from Colorado State University, Fort Collins.

ACKNOWLEDGMENTS

Data for this study were collected in cooperation with the U.S. Department of the Interior, Bureau of Land Management in Nevada and Utah. Special thanks to Dave Schmidt, Steve Langdon, and Jason Teegaurden, former temporary employees of the Intermountain Research Station, who collected most of the field data. The Bureau of Land Management at Ely, NV, provided the inventory data for use in table 3.

RESEARCH SUMMARY

Visual segmentation, a technique for estimating cubic foot volume of woodland tree species, was compared with actual volume measurement. Comparison was made during a forest inventory of pinyon-juniper woodlands in Nevada and Utah. The visual technique's accuracy, its usefulness in developing volume equations, and applicability to volume inventory were studied. This study indicated visual segmentation is not reliable for estimating volume for a single tree. However, a sample of visually estimated volumes proved adequate for developing volume equations. In an application, a bias of 0 to −9 percent of the mean cubic foot volume per acre resulted from summary of 176 plots, using volume equations developed with visually estimated data. An appendix includes a complete description of the visual volume estimation technique for field use.

EXCHANGE Rec'd
DEC 2 1985

Woodland Tree Volume Estimation: A Visual Segmentation Technique

J. David Born
David C. Chojnacky

INTRODUCTION

In the arid Rocky Mountain regions, vast acreages of trees once ignored by foresters are now drawing attention as a source of wood fiber. Of interest are the various species of pinyon, juniper, mountain-mahogany, mesquite, and the evergreen and deciduous oaks. Lowe (1972) grouped these trees in an ecological community known as woodland. In order to assess the wood fiber resource of woodland trees, simple cost-effective volume measurement methods are needed.

Estimating tree volume is a standard concept for foresters, but the shrublike multiple-stem character of woodland species creates new problems that were not considered in the development of volume mensuration methods. Traditional volume measurements, designed for commercial timber species, have focused on the main bole. But a large percentage of the wood in a woodland tree is found in the branches, and frequently a main bole is not well defined.

A cubic measure of wood for all stems and branches is a reasonable approach to assessment of woodland species. In this approach, all linear segments of stem and branch wood are identified, and then volume is calculated for each segment with the appropriate geometric solid formula. Summing the segment volumes produces a volume per tree. However, measuring the necessary diameters and length of each segment is a costly, time-consuming task. For example, a single large juniper tree can have more than 100 1- to 6-foot wood segments.

Rather than measure each tree, sample trees are usually measured for use in constructing volume equations. This then leads to the question of how sample tree volume data can be obtained in an efficient and timely manner for the vast areas of woodlands in the Rocky Mountain States.

BACKGROUND

In previous woodland tree studies, some researchers have estimated wood volume indirectly by first weighing a tree and then converting the weight to volume through specific gravity factors (Felker and others 1983; Weaver and Lund 1982; Miller and others 1981; Storey 1969). Others have cut trees into segments to measure segment diameters and length needed to calculate volume (Howell 1940; Gholz 1980). Weighing trees and cutting trees into sections are suitable techniques for research work where motorized equipment access is good and where the land owner will allow trees to be destroyed for use in a study.

Clendenen (1979) developed volume equations using volume data collected using a method adapted from Cost's (1978) work for measuring volume of standing trees without cutting them down. This method, known as "visual segmentation," does not require a physical measurement of each stem segment (Born and Clendenen 1975). Instead, each segment in a tree is classified into a 2-inch midpoint diameter (outside bark) by 2-foot midpoint length class (since this study, the procedure has been changed to 1-foot length classes). The appendix has a full description of the procedure.

After classification, volumes are computed from the segment diameter class and length class values instead of exact dimensions. Each segment is assumed to be a paraboloid frustum, and Huber's formula (Husch and others 1982, p. 101) is used to compute the volume of each segment:

$$V_i = 0.005454\ H_i D_i^2$$

where

V_i = volume of the ith segment (cubic feet)
H_i = length class of the ith segment (feet)
D_i = diameter class of the ith segment (inches).

Success of visual segmentation is dependent upon (1) correct classification of the segments and (2) the length and diameter class values underestimating and overestimating the actual dimensions in an equal proportion. The following algebraic manipulation of Huber's formula (using class dimensions) illustrates the second point:

$$V = \sum_{i=1}^{n} 0.005454\ (H_i+h_i)(D_i+d_i)^2 \qquad (1)$$

$$= \sum_{i=1}^{n} \{0.005454\ H_i D_i^2\}$$

$$+ \sum_{i=1}^{n} \{d_i[0.005454\ (2D_iH_i+d_iH_i)]$$

$$+ h_i[0.005454\ (D_i+d_i)^2]\} \qquad (2)$$

where

V = volume of a tree (cubic feet)
H_i+h_i = actual length of the ith segment (feet)
D_i+d_i = actual diameter of the ith segment (inches)
h_i = ±deviation (up to 1 foot) of actual segment length from H_i
d_i = ±deviation (up to 1 inch) of actual segment diameter from D_i.

The second summation (Σ) in equation (2) must sum to zero, if the volume of a tree is properly represented by

using class values instead of actual dimensions in Huber's formula. This will happen only if the d_i's and h_i's sum to zero for fixed D_i and H_i. This will occur with greater probability for large n; that is, for trees with many segments or for estimating volume for a group of trees.

The study in this paper compares volume estimates from visual segmentation with volume estimates obtained from exact measurements of segments from trees destructively sampled.

FIELD DATA COLLECTION

In 1980, volume samples were collected for 248 pinyon and juniper trees on lands in Nevada managed by the U.S. Department of the Interior, Bureau of Land Management (BLM). An additional 55 trees were sampled in 1981 on BLM lands in Nevada and Utah. From two to six trees were selected at each of the 61 locations. The locations were a small subsample of the BLM woodland inventory. The sampling was done as a secondary task of a U.S. Department of Agriculture, Forest Service, Forest Survey quality control crew. Because of this, no attempt was made to design the subsample, other than to distribute it throughout the inventory area.

In 1980, trees within the locations were selected in proportion to crown area using transects (Meeuwig and Budy 1981). Because the first year's sample was weak in the larger diameter classes, those taken during the 1981 field season were purposely selected in larger diameter classes. Individual tree measurements included diameter at root collar (DRC), number of stems, crown widths, total height, and location description data (USDA Forest Service 1982). Volume measurements of each tree were obtained by (1) visual segmentation and (2) destructive segmentation.

For visual segmentation, numbers of stem segments were counted in classes of 2-inch midpoint diameter by 2-foot length. The estimator proceeded in a systematic fashion from the base of a tree upward, recording each segment in the appropriate class (see appendix). Two or three visual volume estimates were done for each tree, two by a U.S. Forest Service (FS) quality control crew and usually one by a BLM crew. In 1981, when the last 55 trees were sampled, only the FS crew members made visual volume estimates.

Destructive segmentation involved cutting down trees in order to measure diameter and length dimensions for each segment. Segment lengths were chosen to roughly parallel the visual method, although an exact rule was not established. Tapers of segments were to be less than 15 to 20 percent. Segment length, diameter (outside bark) at both ends, and diameter at the midpoint were recorded for each segment. The destructive segmentation provided data to compute accurate volume estimates for comparison with the visual segmentation estimates.

DATA ANALYSIS AND RESULTS

We investigated three aspects of visual segmentation: (1) its accuracy for estimating volume of individual trees, (2) its usefulness for volume equation development, and (3) the consequences of applying volume equations based on visual segmentation data.

Testing for Accuracy

Before testing, the data were grouped by species, tree size, and estimator group (field crews). Two species—singleleaf pinyon (*Pinus monophylla* Torr. & Frém.) and juniper (*Juniperus osteosperma* [Torr.] Little)—were represented. Four-inch diameter classes were selected to minimize effect of tree size on the comparisons, as trees ranged from 3 to over 20 inches DRC. There were up to three visual volume estimates and a destructive volume estimate for each tree. The crews doing the visual estimating were placed into three groups and called FS1, FS2, and BLM. FS1 was the same estimator for all samples. FS2 included two estimators, one of whom did only 55 of 303 trees. The BLM group included as many as 15 estimators. All estimators attended the same training sessions.

Test statistic.—The statistic used to make the comparisons within groups was the average difference *(diff)* between visual and destructive volume estimates:

$$diff = \sum_{i=1}^{n} \frac{(v_i - d_i)}{n}$$

where

diff = average difference between visual and destructive estimates

v_i = visual volume estimate of the ith tree

d_i = destructive volume estimate of the ith tree

n = sample size for a group.

The visual (v_i) and destructive (d_i) volume estimates were computed by Huber's and Newton's cubic-foot log formulas, respectively (Husch and others 1982, p. 101). Different formulas were used because slightly different measurement procedures were used for visual and destructive volume estimates. Husch points out that Newton's formula is the most flexible and best formula available for logs measured at three diameter points. Because the destructive samples had three diameter measurements, Newton's formula was selected. On the other hand, the visual estimates had only one diameter measurement and were limited to Huber's formula. The difference between the formulas was fairly negligible, as shown by figure 1. The difference, however, is given in table 1 for later use in interpretation of results in table 2.

Background on tests.—Testing for accuracy of a statistic or estimator actually involves testing two components—bias and precision. Bias is the expected difference between any statistic and its true value. In our case, *diff* is the statistic of interest and its true value is zero. A biased statistic from a sample survey cannot be improved by increasing sample size. Precision describes how widely a statistic can fluctuate around its true value. The variance of *diff* is a measure of precision for our statistic. An imprecise statistic can usually be improved by increasing sample size.

Student's t-test can be used to compare visual volume estimates with destructive estimates from the same trees to determine bias, although it is a poor test for

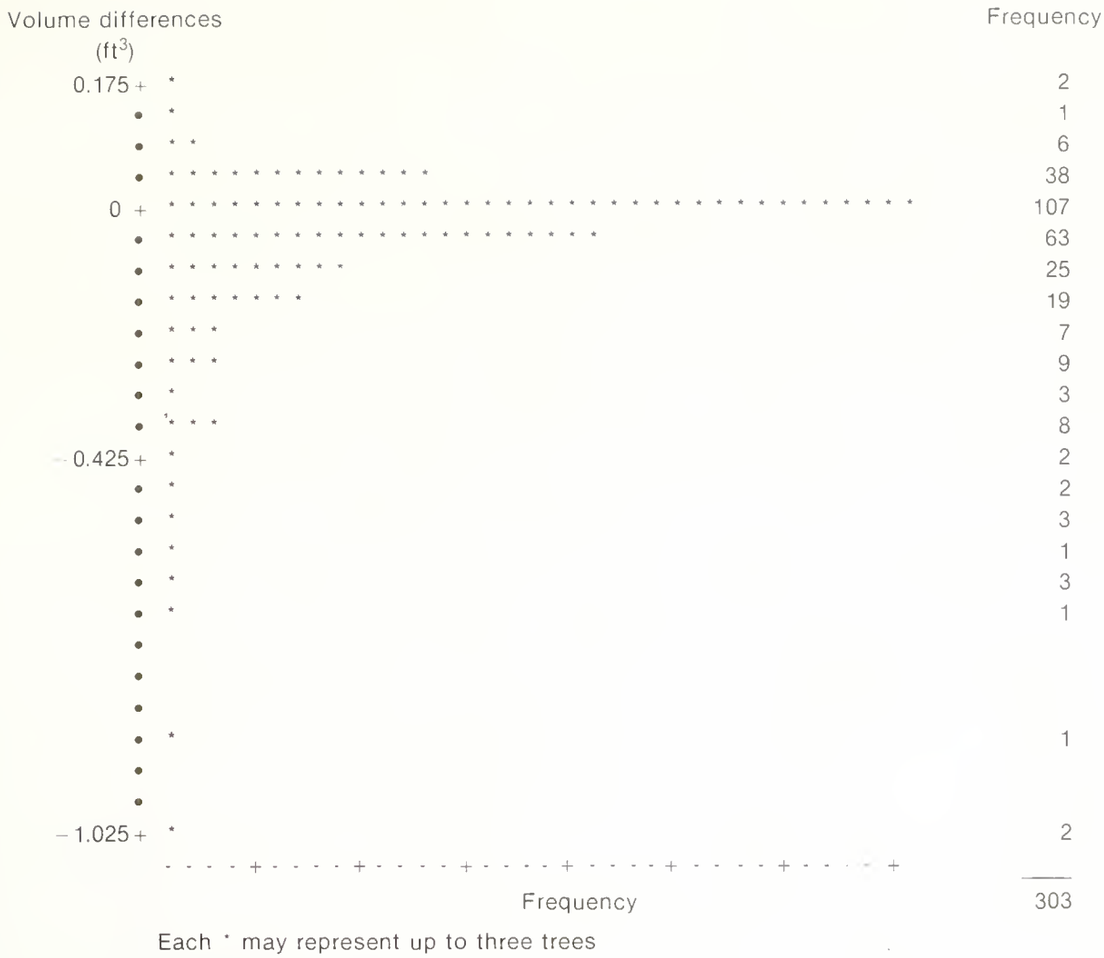


Figure 1.—Frequency distribution (stem-and-leaf plot) between Huber's volume formula and Newton's volume formula applied to the destructive sample data. Volumes for each tree were computed by the two formulas and the difference of Huber's minus Newton's is plotted.

Table 1.—Comparison between wood and bark volume computed by Huber's formula minus volume computed by Newton's formula for destructive sampled trees

Diameter class	Species	Number of trees	Mean volume difference		Median volume difference
DRC inches			*Ft³*	*Percent*[1]	*Ft³*
3 – 6.9	Juniper	23	−0.05	−10	−0.01
	Pinyon	53	−.07	−11	−.05
	Pinyon and juniper	76	−.07	−12	−.04
7 – 10.9	Juniper	51	−.08	−4	−.03
	Pinyon	60	−.12	−3	−.05
	Pinyon and juniper	111	−.10	−3	−.04
11 – 14.9	Juniper	35	−.07	−1	−.03
	Pinyon	32	−.15	−1	−.09
	Pinyon and juniper	67	−.11	−1	−.06
15 – 18.9	Juniper	19	−.03	0	−.01
	Pinyon	16	−.15	0	−.06
	Pinyon and juniper	35	−.08	−1	−.04
>19	Juniper	11	−.05	0	−.01
	Pinyon	3	−.10	0	−.03
	Pinyon and juniper	14	−.06	0	−.01
Total	Juniper	139	−.06	−1	−.02
	Pinyon	164	−.11	−2	−.05
	Pinyon and juniper	303	−.09	−2	−.04

[1]Mean percent difference is the mean volume difference divided by the mean volume computed by Newton's formula.

Table 2.—Comparison between visual segmentation and destructive segmentation using the difference statistic *(diff)*. The confidence intervals (CI's) contain the mean difference (DIFF) unless a 1-in-20 chance in sampling has occurred

Diameter class	Estimator	Number of trees	Mean Volume difference		Volume difference			t-test		Chi-squared	
					Mean	Medium	Minimum	Lower CI	Upper CI	Lower CI	Upper CI
Inches			*Ft³*	Percent[1]	*Ft³*						
					Juniper						
3 – 6.9	BLM	8	−0.04	−6	−0.03	0.51	−0.78	−0.34	0.27	−0.09	0.13
3 – 6.9	FS1	23	0	0	−.05	.94	−1.22	−.17	.16	−.03	.04#
3 – 6.9	FS2	23	−.06	−14	−.06	.25	−.74	−.15	.02	−.08	−.04*
7 – 10.9	BLM	18	−.09	−4	.18	1.58	−4.48	−.76	.59	−.19	.13
7 – 10.9	FS1	51	−.17	−9	−.05	1.58	−4.92	−.42	.09	−.19	−.12*#
7 – 10.9	FS2	51	−.16	−9	−.07	1.08	−4.96	−.39	.08	−.18	−.12*#
11 – 14.9	BLM	18	−.09	−2	−.44	4.16	−2.99	−.87	.69	−.22	.15
11 – 14.9	FS1	35	−.73	−13	−.67	3.49	−3.09	−1.24	−.21*#	−.80	−.61*#
11 – 14.9	FS2	35	−.40	−7	−.17	2.89	−4.63	−.89	.09	−.47	−.30*#
15 – 18.9	BLM	10	−.53	−7	−.49	.78	−2.14	−1.27	.21	−.68	−.14*#
15 – 18.9	FS1	19	.78	9	−.05	21.03	−2.40	−1.64	3.20	.39	1.53*#
15 – 18.9	FS2	19	.88	11	.36	7.28	−1.90	−.26	2.02	.69	1.25*#
> 19	BLM	7	−1.33	−7	.43	5.10	−8.78	−5.51	2.86	−2.14	1.21
> 19	FS1	11	1.39	7	.73	14.48	−5.98	−3.32	6.10	.53	3.47*#
> 19	FS2	11	−2.09	−11	−1.56	11.03	−9.88	−6.06	1.88	−2.85	−.27*#
Total	BLM	61	−.30	−5	−.02	5.10	−8.78	−.78	.19	−.35	−.22*#
Total	FS1	139	−.03	−1	−.07	21.03	−5.98	−.50	.45	−.06	.02
Total	FS2	139	−.21	−5	−.09	11.03	−9.88	−.57	.14	−.24	−.18*#
					Pinyon						
3 – 6.9	BLM	27	.03	5	.05	.52	−.43	−.04	.11#	.02	.05*#
3 – 6.9	FS1	53	.06	10	.03	.64	−.49	0	.12#	.05	.07*#
3 – 6.9	FS2	53	−.04	−7	−.01	.43	−.97	−.09	.01	−.05	−.03*#
7 – 10.9	BLM	33	−.24	−6	−.25	1.69	−2.62	−.62	.14	−.29	−.16*#
7 – 10.9	FS1	60	.14	4	−.11	4.82	−2.27	−.16	.44	.11	.19*#
7 – 10.9	FS2	60	−.39	−10	−.13	1.10	−3.86	−.65	−.13*#	−.42	−.35*#
11 – 14.9	BLM	20	−.62	−6	−.43	3.36	−5.16	−1.47	.24	−.76	−.35*#
11 – 14.9	FS1	31	−1.12	−10	−1.12	4.63	−7.84	−2.10	−.14*	−1.27	−.88*#
11 – 14.9	FS2	31	−1.41	−13	−1.63	2.06	−5.67	−2.11	−.71*#	−1.53	−1.21*#
15 – 18.9	BLM	8	−2.96	−13	−2.59	3.83	−13.69	−8.20	2.27	−4.05	.15
15 – 18.9	FS1	16	−.26	−1	−.71	10.85	−10.01	−3.31	2.79	−.76	.78
15 – 18.9	FS2	16	−1.42	−5	−1.35	5.81	−9.23	−3.24	.40	−1.75	−.75*#
> 19	BLM	1	7.68	13	7.68	7.68	7.68			.91	27.72*#
> 19	FS1	3	−6.19	−12	−4.85	−4.80	−8.93	−12.09	−.30*#	−8.60	8.96
> 19	FS2	3	−1.89	−4	−2.08	.61	−4.20	−7.88	4.10	−2.90	4.48
Total	BLM	89	−.40	−6	−.03	7.68	−13.69	−.90	.11	−.44	−.34*#
Total	FS1	163	−.28	−4	−.03	10.85	−10.01	−.65	.09	−.31	−.25*#
Total	FS2	163	−.60	−8	−.11	5.81	−9.23	−.84	−.35*#	−.62	−.58*#
					Pinyon and juniper						
Total	BLM	150	−.36	−6	−.03	7.68	−13.69	−.71	−.01*	−.38	−.32*#
Total[2]	FS1	302	−.16	−3	−.05	21.03	−10.01	−.46	.13	−.18	−.15*#
Total[2]	FS2	302	−.42	−7	−.11	11.03	−9.88	−.63	−.21*#	−.43	−.41*#

*Ninety-five percent confidence interval does not contain zero.
#Ninety-five percent confidence interval does not contain the negative value from table 1.
[1]Mean percent difference is the mean volume difference divided by the mean volume computed by Newton's formula.
[2]This total for number of trees does not equal the totals in figure 1 and table 1 because of a data collection error in omitting visual segmentation of one tree.

precision. Freese (1960) suggests a chi-square test if both bias and precision are of concern.

All statistical analyses are done in terms of 95 percent confidence intervals instead of testing single point estimates. Confidence intervals give more information than simple tests that just accept or reject a hypothesis. Also, confidence intervals allow the reader to select either zero or a value from table 1 as the test criterion. A 95 percent confidence interval can be interpreted as an interval having a 19-in-20 chance for containing the true population value.

The t-test for paired differences is given in Steel and Torrie (1960) and can be expressed in terms of a 95 percent confidence interval:

$$\text{Prob}\left([diff - (t_{0.025:n-1}S_d)] \leq \text{DIFF} \leq [diff + (t_{0.025:n-1}S_d)]\right) = 95\%$$

where

t = the value obtained from a t-table at $\alpha = 0.025$ probability level for n−1 degrees of freedom

S_d = the standard error of the mean difference (*diff*)

n = the sample size of the groups of differences being tested

DIFF = the expected (true population) value of *diff* (it is either zero or the values in table 1).

Freese (1960) gave a computing formula for the chi-square test, but not in the form of a confidence interval.

The pivotal-quantity method (Mood and others 1974, p. 379) was used to derive the following 95 percent confidence interval:

$$\text{Prob}\left(\left[diff - \frac{1.96}{n}\sqrt{\frac{diffsq}{\chi^2_{0.025:n}}}\right] \leq \text{DIFF} \leq \left[diff + \frac{1.96}{n}\sqrt{\frac{diffsq}{\chi^2_{0.975:n}}}\right]\right) = 95\%$$

where

χ^2 = values obtained from a chi-square table at the 0.025 and 0.975 probability levels for n degrees of freedom

$$diffsq = \sum_{i=1}^{n} (v_i - d_i)^2.$$

Accuracy test results.—Results on the accuracy of visual segmentation are given in table 2 for each of the three estimators. The mean differences *(diff)* are mostly negative and range from −3 to −7 percent for the pinyon and juniper totaled over all diameter classes. Median, maximum, and minimum differences are also given. The median tends to be closer to zero than the mean. The maximum and minimum illustrate the extremes that can result from visual segmentation.

According to the t-test confidence intervals, the mean population difference (of visual minus destructive estimates) could be zero for most diameter class groups. The most noteworthy exceptions are for totals having mean differences larger than −6 percent. For individual diameter classes, −10 to −13 percent differences are required in order to have t-test significance.

The chi-square test, on the other hand, shows that the mean population differences would rarely include zero. This conservative test is more sensitive to the large variation found in each individual visual estimate.

These results indicate that visual segmentation tends to be unbiased (according to t-test) but is inaccurate (according to chi-square test) for estimating volume for a single tree. In the table 2 confidence interval tests, substituting mean percent differences given in table 1 for zero does not significantly alter results. However, our use of Newton's formula to compute volume in destructive segmentation probably contributes somewhat to the negative values consistently observed in table 2 for the mean difference between visual and destructive segmentation.

Volume Equations

The visual segmentation method was not intended to provide accurate volume predictions for single trees. We primarily devised it to provide large amounts of inexpensive data for volume equation development. Neter and Wasserman (1974) point out that measurement errors in a dependent variable used for regression modeling will present no problems if the errors are random. In our case, this means the visual estimates must vary in a random manner. This assumption can easily be examined by comparing regression volume equations developed from both the visual and destructive sample data.

A simple regression model using only DRC and height as predictor variables was selected for the comparison. Other variables were available, but they added little to the predictive power of DRC and height. Combining DRC and height into one variable, DRC squared times height (DRSQH) worked well. A natural log transformation of the data was made to minimize the increasing variance of the volume data with increasing tree size and to satisfy general linear model theory requirements for hypothesis testing. The log-transformed model may not be the best approach for developing pinyon-juniper volume equations, but it was adequate for our evaluation of visual segmentation.

In figures 2 and 3, regression equations in natural log units for all groups are compared against the 95 percent confidence bands for individual predictions from destructive sample data. It is hard to distinguish differences between the four regression lines, as all lie well within the 95 confidence bands. However, results expressed in the log-transformed units can be deceptive for making inference in cubic feet.

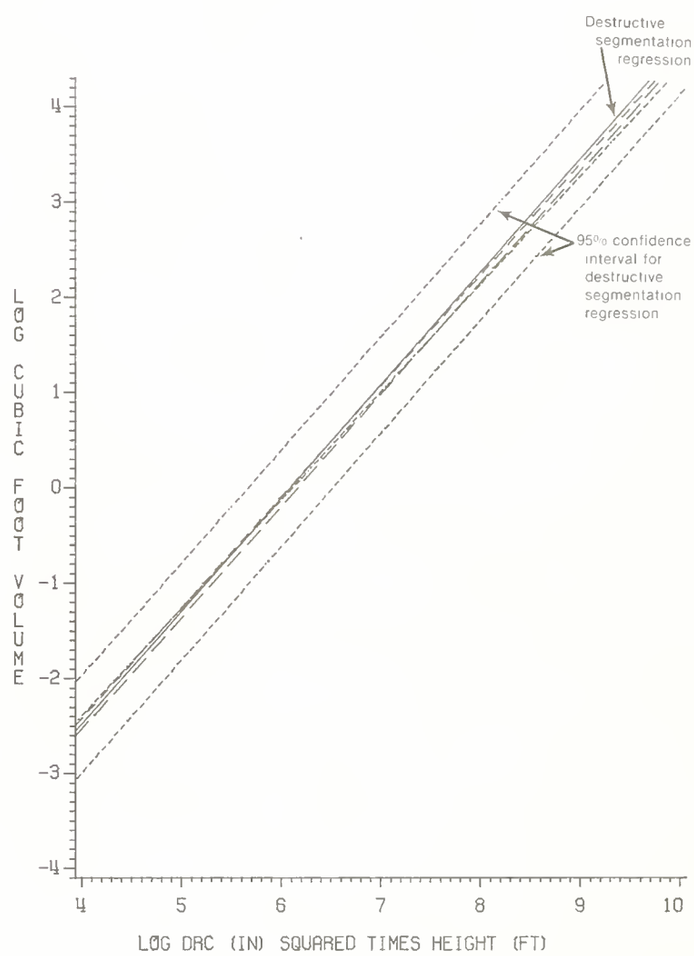


Figure 2.—Pinyon destructive segmentation data in log units with regression line (solid line) and 95 percent confidence bands (for individual predicted values) fit to data. Three dashed lines representing regression equations for visual estimates are overlaid.

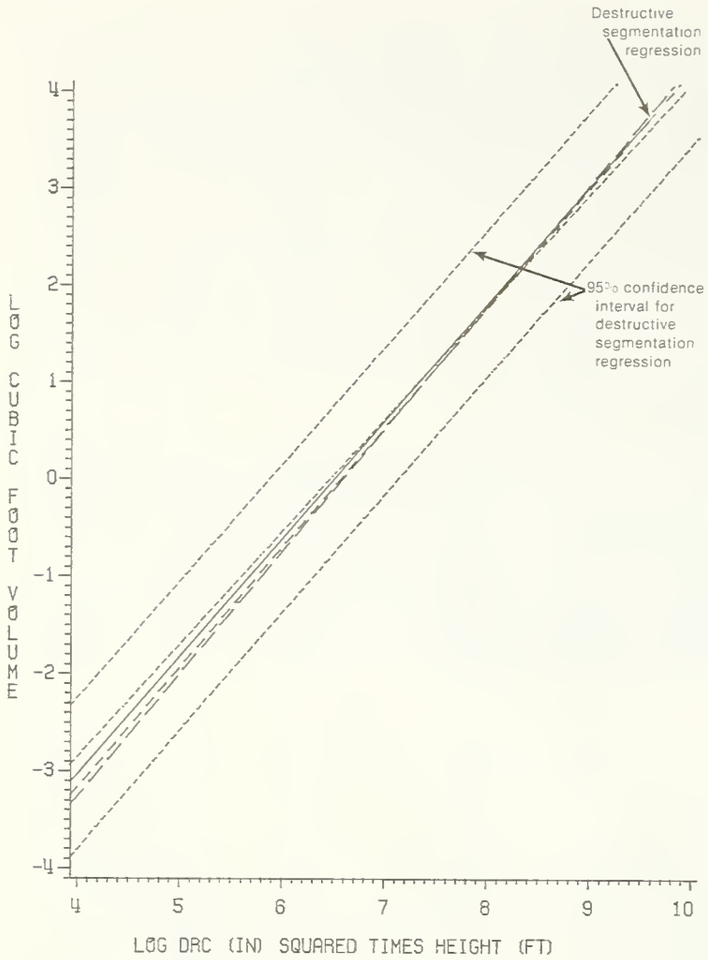


Figure 3.—Juniper destructive segmentation data in log units with regression line (solid line) and 95 percent confidence bands (for individual predicted values) fit to data. Three dashed lines representing regression equations for visual estimates are overlaid.

Figures 4 and 5 illustrate the equation predictions converted back to cubic feet. Now, a tendency toward a negative bias is evident for the pinyon equations. The graph of the juniper equations indicates less bias than observed for pinyon.

The volume equations based on the visual data are surprisingly close to the equation based on the destructive data. However, a small negative bias is evident in figures 2 to 5. This corresponds to the previous findings in table 2.

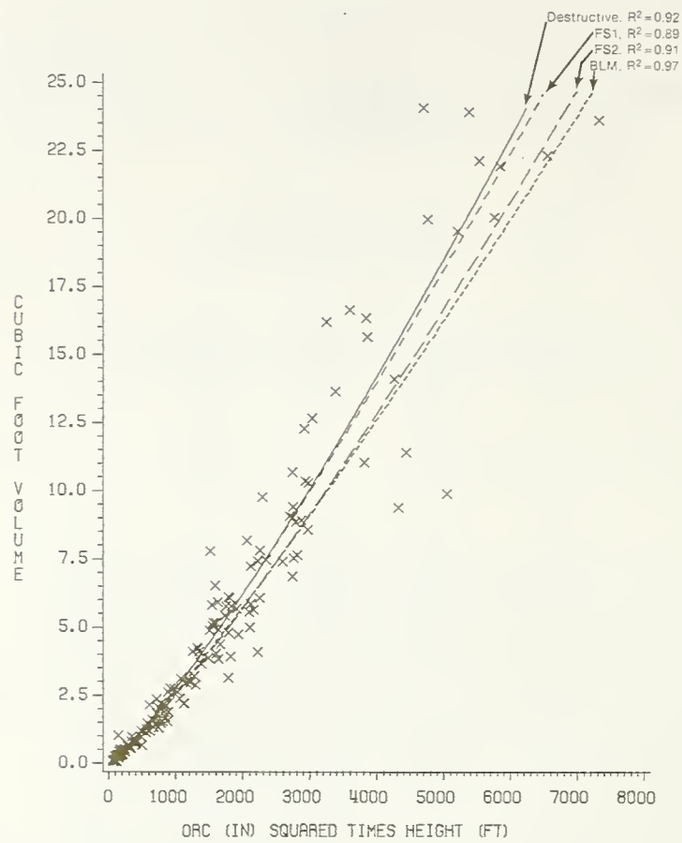


Figure 4.—Pinyon destructive segmentation data in cubic feet with a regression curve (solid line) and three curves for visual estimates overlaid.

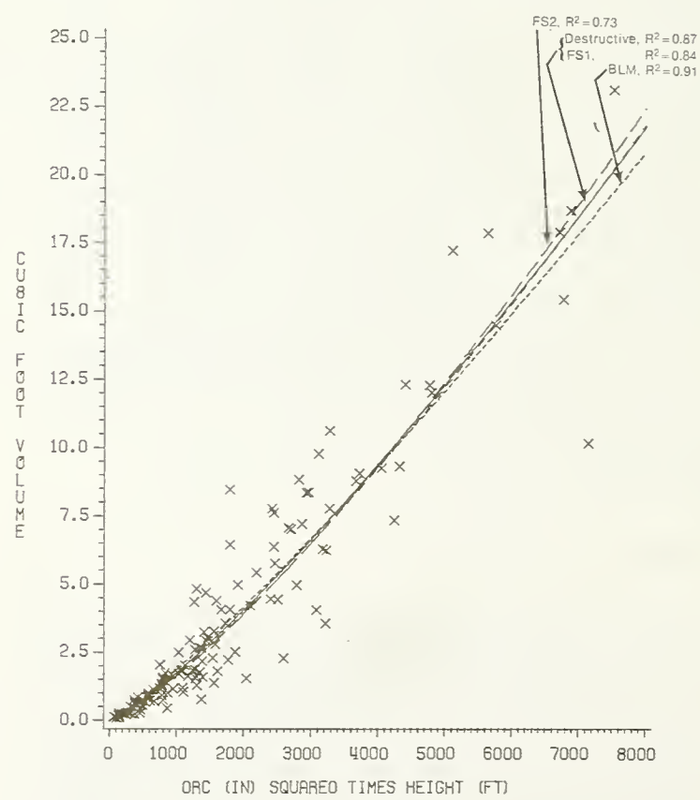


Figure 5.—Juniper destructive segmentation data in cubic feet with a regression curve (solid line) and three curves for visual estimates overlaid.

An Application

Even a small volume bias can compound rapidly when summing many trees in an inventory. An additional data set was used to examine the bias observed in the volume equations in figures 2 to 5. We used 176 plots of 0.1 acre each from the Schell Resource Area of the Ely, NV, BLM District, to compare predictions of the volume equations for the estimator groups. The plots were taken from a systematic grid at a sampling fraction of 0.1 acre for each 6,177 acres. The Schell data are within the sample population for this study and include the same two pinyon and juniper species.

Table 3 shows a summary for average cubic foot volume per acre (computed from the four equations in figs. 4 and 5) for the Schell Resource Area. The mean volumes per acre for each estimator look reasonably similar. However, most of the per-acre means, computed from volume equations based on visual data, underestimate volume when compared to the destructive equations. Overall, a negative bias as high as −9 percent (for pinyon, for BLM and FS2) resulted from using visual segmentation as opposed to destructive segmentation for estimating population means. Results tended to be better for juniper than for pinyon.

DISCUSSION

Should visual segmentation be used in a woodland inventory to estimate volume? This study shows it is a useful technique, but, like any subjective method, it should be used with caution. Estimators tend both to overestimate and underestimate volumes visually, with underestimates more common. Juniper fared better than pinyon, perhaps because juniper trees usually have more segments per tree than do pinyon. From the theory behind visual segmentation, more segments per tree give the technique higher probability of success (see equation 2). Applications of visual segmentation to real data showed a 0 to −9 percent bias in estimating mean volume per acre.

Perhaps doing more than one visual estimate per tree for fewer trees would be an effective way to reduce the bias rather than estimating many trees once. Table 4 shows the improvement by grouping estimates. The median or mean of three estimates appears to be the best for the Nevada data.

The theory behind visual segmentation appears sound, based on the good results from estimator FS1. However, the less consistent performance of the BLM estimator is probably closer to production mode reality. But with proper quality control, visual segmentation is certainly worth consideration. Our more recent experience indicates that intense training, consistent use of the segment poles, and quality control checks on estimators significantly improves the quality of the visual data.

We would like to make a final point somewhat unrelated to this study but important for application of visual segmentation to volume equation construction. Even if the bias from visually measuring pinyon-juniper volume was entirely eliminated, the procedure would not be completely satisfying for developing volume equations. This is because the relationship between pinyon-juniper tree volume and easily measured variables is not well understood.

Table 3.—Summary of 176 forested plots from the Schell Resource Area of the Ely BLM District. Volumes for each tree were computed using volume equations developed for each estimator group

Species	Diameter class	Volume per acre				Sampling error[1]	Percent of plots having trees[2]
		BLM	FS1	FS2	Destructive		
	Inches	*Ft³*				*Percent*	
Juniper	3 – 6.9	9.8	8.0	7.5	8.6	±22	68
Juniper	7 – 10.9	37.4	33.6	32.6	35.2	±22	65
Juniper	11 – 14.9	52.1	49.5	49.1	50.9	±19	57
Juniper	15 – 18.9	69.7	69.4	70.1	70.3	±22	46
Juniper	>19	131.3	138.5	142.9	137.8	±28	38
Juniper	Total	300.3	299.0	302.2	302.8	±17	89
Pinyon	3 – 6.9	32.4	33.2	30.0	31.9	±21	78
Pinyon	7 – 10.9	76.3	81.6	74.4	81.0	±21	64
Pinyon	11 – 14.9	70.4	77.6	71.2	78.6	±28	38
Pinyon	15 – 18.9	55.2	62.3	57.5	64.1	±38	19
Pinyon	>19	26.1	29.8	27.6	30.9	±56	7
Pinyon	Total	260.4	284.5	260.7	286.5	±18	84
Pinyon and juniper	Total	560.7	583.5	562.9	589.3	±13	100
	Volume Bias[3] as Compared to the Destructive Equation						
Juniper	Total	−1%	−1%	0%		±17	89
Pinyon	Total	−9%	−1%	−9%		±18	84
Pinyon and juniper	Total	−5%	−1%	−4%		±13	100

[1]The sampling error is a t-statistic confidence interval, expressed as a percent of the sample mean, that contains the population mean unless a 1-in-20 chance occurs in selecting the sample. The errors were the same for all four volume estimates in a diameter class.

[2]This refers to the percentage of plots having trees for that diameter class. The volume was set to zero in the variance computation for the plots having no trees in a given diameter class.

[3]Bias is defined as a visual estimate (BLM, FS1, or FS2) minus the destructive estimate, divided by the destructive estimate.

Table 4.—Effect of grouping several visual volume estimates for a tree, pinyon and juniper are combined

Diameter class	Mean of FS1 and FS2[1]	Mean of FS1, FS2, and BLM	Median of FS1, FS2, and BLM	Range of percent errors for single estimates[2]
3 – 6.9	–0.003 [–1%] 76	0.006 [1%]35	–0.008 [–1%]35	– 8 to 7
7 – 10.9	–.141 [–5%]111	–.070 [–2%]50	–.223 [–7%]50	–10 to 0
11 – 14.9	–.894 [–11%] 66	–.455 [–6%]38	–.688 [–9%]38	–11 to –5
15 – 18.9	.068 [1%] 35	.521 [4%]18	.484 [3%]18	–11 to 2
>19	–1.422 [–5%] 14	.417 [2%] 8	–.350 [–1%] 8	– 8 to –1

[1]Mean visual volume difference, followed in brackets by mean difference expressed as a mean percent of destructive volume, followed by sample size.

[2]This is the range of errors corresponding to the value in brackets for FS1, FS2, and BLM kept separately.

For example, our volume equation using destructive segmentation had rather large confidence intervals. The confidence bands in figures 2 and 3 correspond to roughly ±40 and ±50 percent of the predicted cubic foot volume for a single pinyon and juniper, respectively. This implies much variation in the data. As a result, our volume equation coefficients are the best "least squares" coefficients for the mix of diverse tree forms in our sample data. A slightly different mix of tree forms could result in much different regression coefficients. In other words, we suggest that volume equations based on visual segmentation only be used in the local areas where the segmentation data were collected. This practice will reduce the probability of extrapolation errors from use of an inappropriate volume equation. The ease and simplicity of the visual segmentation procedure allows the option to develop new volume equations or at least check existing equations for use in any woodland inventory or cruise.

REFERENCES

Born, J. D.; Clendenen, G. W. Study plan: measurement of volume and product potential for pinyon and juniper trees in northern New Mexico. 1975. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forest Survey, Ogden, UT.

Clendenen, G. W. Gross cubic-volume equations and tables, outside bark for pinyon and juniper trees in northern New Mexico. Research Paper INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 21 p.

Cost, N. D. Multiresource inventories—a technique for measuring volumes in standing trees. Research Paper SE-196. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1978. 18 p.

Felker, P.; Cannell, G. H.; Clark, P. R.; [and others]. Biomass production of *Prosopis* species (mesquite), *Leucaena*, and other leguminous trees grown under heat/drought stress. Forest Science. 29(3): 592-606; 1983.

Freese, F. Testing accuracy. Forest Science. 6(2): 139-145; 1960.

Gholz, H. L. Structure and productivity of *Juniperus occidentalis* in central Oregon. The American Midland Naturalist. 103(2): 251-261; 1980.

Howell, J. Pinyon and juniper: a preliminary study of volume, growth, and yield. Regional Bulletin 71. Albuquerque, NM: U.S. Department of Agriculture, Soil Conservation Service; 1940. 90 p.

Husch, B.; Miller, C. I.; Beers, T. W. Forest mensuration. 3d ed. New York: Ronald Press Company; 1982. 402 p.

Lowe, C. E. The vertebrates of Arizona. Tucson: University of Arizona Press; 1972. 270 p.

Meeuwig, R. O.; Budy, J. D. Point and line-intersect sampling in pinyon-juniper woodlands. Research Paper INT-104. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 38 p.

Miller, E. L.; Meeuwig, R. O.; Budy, J. D. Biomass of singleleaf pinyon and juniper. Research Paper INT-273. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 18 p.

McClure, J. P. Sectional aluminum poles improve length measurements in standing trees. Research Note SE-98. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1968. 4 p.

Mood, A. M.; Graybill, F. A.; Boes, D. C. Introductory to the theory of statistics. 3d ed. New York: McGraw-Hill; 1974. 564 p.

Neter, J.; Wasserman, W. Applied linear statistical models. Homewood, IL: Richard D. Irwin, Inc.; 1974. 842 p.

Steel, R. G.; Torrie, J. H. Principles and procedures of statistics. New York: McGraw-Hill; 1960. 481 p.

Storey, T. G. Tree weights and fuel size distribution of pinyon pine and Utah juniper. In: Project Flambeau. . . an investigation of mass fire (1964-1967). Final report—vol. III, appendices. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1969: 15-32.

U.S. Department of Agriculture, Forest Service. Resources Evaluation Nevada-Utah forest survey field procedures. 1982. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forest Survey, Ogden, UT.

Weaver, T.; Lund, R. Diameter-weight relationships for juniper from wet and dry sites. Great Basin Naturalist. 42(1): 73-76; 1982.

APPENDIX: WOODLAND TREE VISUAL SEGMENTATION PROCEDURE

This appendix contains a field procedure for visually estimating cubic foot volume of woodland tree species. The procedure is updated slightly over that used for the data collected in this study. The main difference is that the segment length classes were changed from 2-foot to 1-foot intervals. Species included for the Rocky Mountain States are all hardwoods except aspen and cottonwood, and pinyon and juniper softwoods.

What To Segment

Trees to be measured for volume must have at least one live stem 3 inches or larger in diameter at the root collar (DRC) measurement point. A stem, as opposed to a branch, generally grows in an upright position and contributes to the main structural support of a tree crown. All stems, branches, and bark, whether live or dead, are included. Even severed branches lying on the ground are measured. If a tree portion is missing (from fencepost cutting, firewood cutting, and so forth), estimate the size of the missing portion and record the missing segments. Omit a tree if more than half is missing or if it is unreasonable to estimate the missing parts.

A woodland tree is defined as a woodland species capable of yielding at least one stem 3 inches or larger DRC with at least 8 feet of wood meeting minimum segment size standards. Tree species not meeting these specifications are considered brush form and are not inventoried as trees.

In practice, trees meeting the specifications must presently or potentially stock an area of at least 1 acre surrounding a sample plot for the vegetation to qualify as forest. Present stocking of tree form vegetation, or evidence of prior stocking, must exceed 10 percent crown cover for minimum stocking, and each individual species must have the potential to meet tree form specifications for the species to be included.

What Is a Segment?

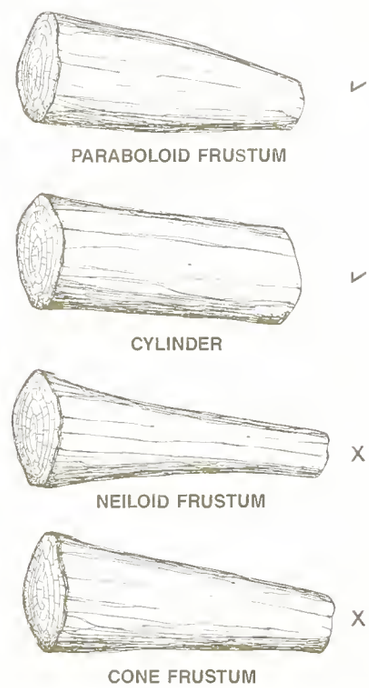
A segment is a piece of wood classified by midpoint of length and diameter. The 1-foot length and 2-inch diameter classes are:

1-foot length classes		2-inch diameter classes	
Midpoint class	Actual lengths	Midpoint class	Actual diameters (outside bark)
1	1-1.49	2	1.5- 2.9
2	1.5-2.49	4	3- 4.9
3	2.5-3.49	6	5- 6.9
4	3.5-4.49	8	7- 8.9
5	4.5-5.49	10	9-10.9
6	5.5-6.49	12	11-12.9
		14	13-14.9
		16	15-16.9
		etc.	

The field estimator chooses the actual segment dimensions by visually dividing stem and branch wood into consecutive lengths for classification. Success of the segmentation procedure is completely dependent upon the good judgment and care exercised by the estimator.

To qualify, a segment must be at least 1.5 inches at midpoint diameter, 1.5 inches at the small end diameter, and 1 foot in total length. Unless the segment is a cylinder, the minimum midpoint diameter will be larger than 1.5 inches. Segments may be any diameter (class), but lengths are limited to 6 feet maximum to minimize errors in estimating dimensions and in computing volume.

As a rule of thumb, segments should be selected so they approximate a paraboloid frustum or a cylinder. Avoid breaking a stem or branch into segments that look like neiloid or cone frustums.



When in doubt, always select short segments (<3 feet) because they will minimize errors due to odd shapes when calculating volume. Keep in mind that length class spans a 1-foot interval and the diameter class spans a 2-inch interval. For greatest accuracy, choose segment lengths as close to the class midpoint as possible. Occasionally segments must be "adjusted" to fit length categories by mentally moving sections from one segment to an adjacent segment. This is likely to occur around forks or other abrupt changes in segment form. Care must also be exercised when classifying lengths of segments from branches originating at angles less than 45 degrees. The length class should be the average length of the upper and lower sides.

How To Segment

A systematic method is used to (1) avoid omitting segments and (2) avoid recording a segment more than once. Begin visual segmentation on the main stem at the ground line. On multiple stem trees, begin segmentation with the smallest DRC stem. Proceed up the stem until you encounter a branch that contains a qualifying segment(s) or the stem forks. Make sure all branches having

Figure 6.—The order of segment tallies.

a 1.5-inch minimum diameter that qualify as segments are counted as you proceed up a stem. Do not back up and guess the size of small segments after all large stems have been tallied (previous estimators have made large errors by miscounting small segments). Whenever a fork is encountered, always proceed up the smaller stem first, then return to the fork and proceed up the larger stem.

Figure 6 contains diagrams illustrating the order of tallying segments. The numbers indicate the order of tallying.

Field Estimation of the Segments

Classification of the segments is best done with aid of "segment poles," 1-inch square aluminum tubes 5 feet long, scaled with colored tape (see fig. 7). (The segment poles are a modification of McClure's [1968] tree height poles.) Red 1-foot and yellow ½-foot marks on the poles aid the estimation of segment lengths. Alternating yellow and black 2- and 4-inch wide bands at the pole's base aid in estimating segment diameters. A segment pole is placed against the lower stem and branches (where most of the wood is found) for correct length classification. A peg in one end of each pole permits the poles to be connected together and placed upward into a tree crown. Also, use of the segment pole should eliminate diameter misclassification of segments within the lower portion of the tree. The midpoint diameters of large segments (10 inches and larger) that are within reach should be measured with a diameter tape.

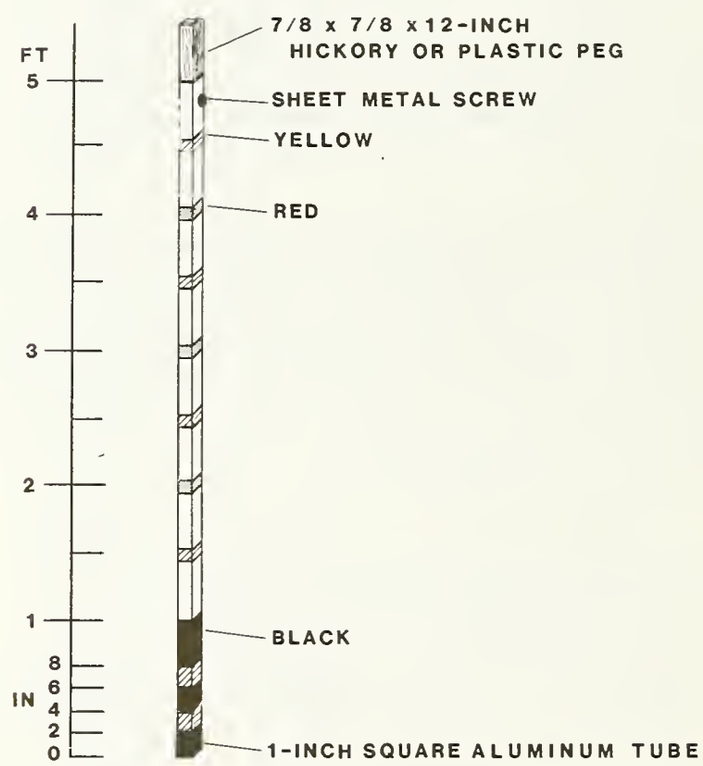


Figure 7.—A construction diagram for a "segment pole" made of 1-inch-square aluminum tubing.

How to Record Segments

Tally segments on the tree segmentation form by using the dot count method (see fig. 8). Blank forms at the end of this publication are included for use by the reader. For segments with diameters larger than 16

WOODLAND TREE SEGMENTATION RECORD

State/County 0 8 1 0 3 7 (1 2 3 4 5)

NFS Region/ BIA Area/ BLM Resource Area 0 (6)

Forest/ Agency/ District 9 9 (7 8)

Subunit/ Reservation/ Planning Unit 0 5 (9 10)

Location No. 0 1 2 3 (11 12 13 14)

Owner 7 0 (15 16)

Sample Area 0 3 (17 18)

Date 6-25-85

Crew D. Recorder, C. Cruiser

Pt. No. 0 3 Tree No. 0 1 Species 1 3 3 DRC 1 2 5 No. Stems 0 1

Total Ht. 1 6 No. Segments 0 1 4 Radial Growth 0 6 Estimator 0 1

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2	3		1	1									5
	3			1										1
	4	2	5			1								8
	5													
	6													
TOTAL		5	5	2	1	1								14
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2	⁝		·	·									5
	3			·										1
	4	··	⁝⁝			·								8
	5													
	6													

Pt. No. 0 4 Tree No. 0 7 Species 0 6 5 DRC 3 4 4 No. Stems 0 4

Total Ht. 3 2 No. Segments 1 0 9 Radial Growth 0 4 Estimator 0 1

Record Multiple Stems DRC Below

13.6	14.7	16.5	27.6		

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16	20				T
SUMMARY	1	12	2											14
	2	16	12	14	1		1		1					45
	3	3	12	1	6									22
	4	2	4	3	3	2	2							16
	5			3		4	2	1						10
	6				1					1				2
TOTAL		33	30	21	11	6	5	1	1	1				109
DOT COUNT		2	4	6	8	10	12	14	16					T
	1	⊠··	··											14
	2	⊠⁝	⊠··	⊠⁝	·		·		·					45
	3	⁝	⊠··	·	⁝									22
	4	··	⁝⁝	··	··	⁝	⁝							16
	5			⁝		⁝⁝	⁝	·						10
	6				·					·				2

Figure 8.—An example of segmentation recording form.

inches, blank spaces are provided to specify the correct 2-inch diameter class, such as 18, 20, 22, or 24. When a tree has been completed, summarize the dot counts in the space provided. Total all columns and rows and enter this figure under heading TOTAL (T). Also enter the grand total segment count in the header information.

Definitions

DRC.—The diameter to the nearest 0.1 inch of a tree at just above the root collar or ground line. DRC is measured at the ground line for single-stem trees with uniform stem taper. If a tree forks near or below the ground line, a DRC of each stem is measured and an equivalent DRC (EDRC) is computed and recorded in place of DRC:

$$EDRC = \sqrt{\sum_{i=1}^{n} DRC_i^2}$$

where

n = number of stems

DRC_i = diameter of the ith stem.

Although a tree must have at least one stem 3 inches DRC or larger to be segmented, the EDRC computation may include stems less than 3 inches DRC if these stems support qualifying segments. Space is provided for recording multiple diameters for later calculation and for checking the data.

Situations often occur that require judgment in determining the point of diameter measurement. DRC or EDRC is used to compute the basal area of stems supporting the total stem and branch volume of a tree. Thus, DRC or EDRC should be measured at the lowest point on a tree where it best represents the basal area supporting that tree. In other words, the measurements should be taken at the lowest point consistent with the taper of the stem(s) in a tree. Do not include butt swell or other abnormalities that will increase the diameter over that taken at the base of a stem(s) with uniform taper. Move the measurement point up the tree as needed to obtain a reasonable measurement.

When a tree forks near the base, EDRC should be computed from the stems above the fork if a single measurement near the base would obviously inflate the value. A tree forking just above the ground could often be measured at the base as a single-stem tree, but space between the stems will usually inflate the measurement. On the other hand, moving too far up a tree to measure stems above a fork could give an unreasonably small measurement to represent the base of that tree. See figure 9 for examples of DRC and EDRC measurement points.

No. stems.—A count of the number of basal stems used for DRC or EDRC measurements. Stems, as compared to branches, provide structural support for a major portion of a tree.

Qualifying segment.—A piece of wood at least 1 foot long and at least 1.5 inches in diameter (outside bark) at the small end.

Total ht.—The total height of a tree measured perpendicular to the ground line to the nearest 1 foot. For multiple-stem trees, the height of the tallest stem is measured.

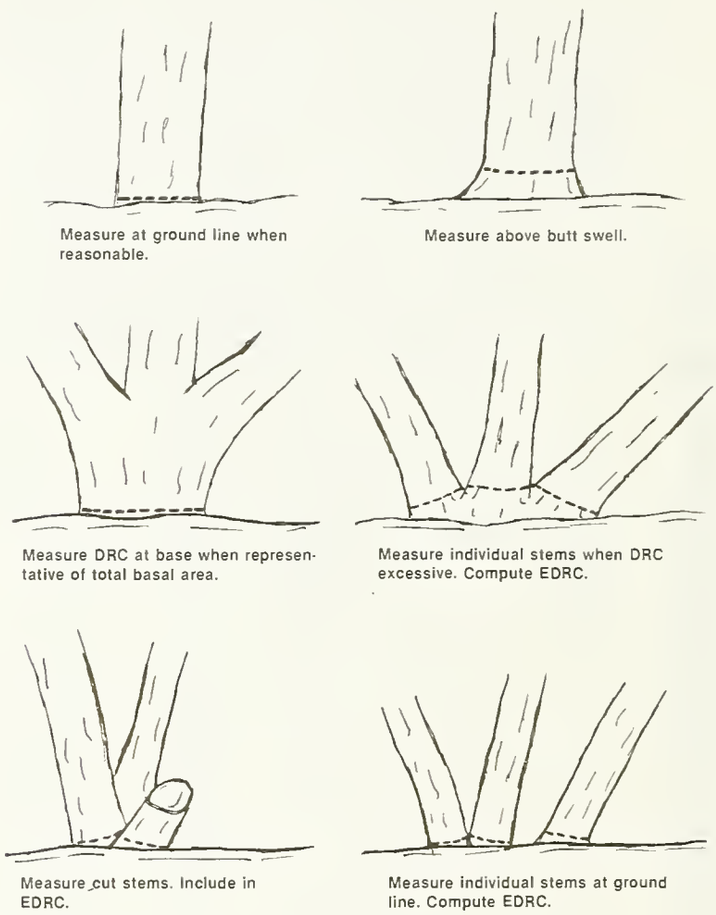


Figure 9.—Examples of DRC and EDRC measurements.

WOODLAND TREE SEGMENTATION RECORD

State/County ___ ___ / ___ ___ ___ (1 2 / 3 4 5)

NFS Region/ BIA Area/ BLM Resource Area ___ (6)

Forest/ Agency/ District ___ ___ (7 8)

Subunit/ Reservation/ Planning Unit ___ ___ (9 10)

Location No. ___ ___ ___ ___ (11 12 13 14)

Owner ___ ___ (15 16)

Sample Area ___ ___ (17 18)

Date _____

Crew _____

Pt. No. ___ Tree No. ___ Species ___ DRC ___ No. Stems ___

Total Ht. ___ No. Segments ___ Radial Growth ___ Estimator ___

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														

DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. ___ Tree No. ___ Species ___ DRC ___ No. Stems ___

Total Ht. ___ No. Segments ___ Radial Growth ___ Estimator ___

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														

DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

WOODLAND TREE SEGMENTATION RECORD

State/County ___ ___ / ___ ___ ___ (1 2 / 3 4 5)

NFS Region/ BIA Area/ BLM Resource Area ___ (6)

Forest/ Agency/ District ___ ___ (7 8)

Subunit/ Reservation/ Planning Unit ___ ___ (9 10)

Location No. ___ ___ ___ ___ (11 12 13 14)

Owner ___ ___ (15 16)

Sample Area ___ ___ (17 18)

Date _____

Crew _____

Pt. No. ___ Tree No. ___ Species ___ DRC ___ No. Stems ___

Total Ht. ___ No. Segments ___ Radial Growth ___ Estimator ___

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. ___ Tree No. ___ Species ___ DRC ___ No. Stems ___

Total Ht. ___ No. Segments ___ Radial Growth ___ Estimator ___

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Pt. No. Tree No. Species DRC No. Stems

Total Ht. No. Segments Radial Growth Estimator

Record Multiple Stems DRC Below

1 - Foot Length Class		2 - Inch Segment Midpoint Diameter Class												
		2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2													
	3													
	4													
	5													
	6													
TOTAL														
DOT COUNT		2	4	6	8	10	12	14	16					T
	1													
	2													
	3													
	4													
	5													
	6													

Born, J. David; Chojnacky, David C. Woodland tree volume estimation: a visual segmentation technique. Research Paper INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 16 p.

Visual segmentation, a technique for estimating cubic foot volume of woodland tree species, was compared with actual volume measurement. Results indicate that visual segmentation data are useful for developing volume equations.

KEYWORDS: pinyon, juniper, inventory

The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station's primary area includes Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Several Station research units work in additional western States, or have missions that are national in scope.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1985—576-040/20,000 REGION NO. 8